THE INDOMITABLE EVOLUTIONIST: LYNN MARGULIS

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The evolutionary biologist Lynn Margulis is best known for her work on the Serial Endosymbiotic Theory (SET) to explain the origins of eukaryotic cells. This article presents key facets in the life of this *avant-garde* biologist and her work that has changed the way we perceive life on Earth.

"To me, the human move to take responsibility for the living Earth is laughable — the rhetoric of the powerless. The planet takes care of us, not we of it. Our self-inflated moral imperative to guide a wayward Earth, or heal our sick planet, is evidence of our immense capacity for self-delusion. Rather, we need to protect ourselves from ourselves."

This very courageous statement that challenges the self-acclaimed supremacy of humans over nature was made by Lynn Margulis (refer **Fig.1**). She is believed to be one of the most creative scientific theorists of the modern era, who transformed the idea of how life evolved on Earth. Many of her contemporaries, including the famous socio-biologist E.O Wilson, have acknowledged her as being the 'most successful synthetic thinkers of modern Biology' due to her holistic approach towards the idea of evolution.

Early life and education

Born on March 5th, 1938, in Chicago, Lynn was the eldest of the four daughters of Morris Alexander, a lawyer and businessman, and Leone Alexander who ran a travel agency. At the age of 15, she completed her education at Hyde Park High School, and got enrolled in a special early admission program at the University of Chicago (UC). There, Lynn had the opportunity to read the original works of many famous scientists, which furthered her interest in science. In 1957, she graduated with a degree in Liberal Arts, and moved to the University of Wisconsin to study Biology under Walter Plaut (who was to become her supervisor) and Hans Ris. In 1960, she graduated with an MS degree in Zoology and Genetics. She then began her research career in the University of California, under the guidance of Max Alfert, earning her doctoral degree in 1965. Lynn was offered her first job — a research assistantship and the position of a lecturer in Brandeis University — even before she could finish her dissertation. However, it was only after she had been awarded a PhD that she moved to Boston University, where she taught Biology for 22 years. She had a remarkable career, going on to become a Distinguished Professor of Geosciences — a position she held till her death in 2011.

Important influences

While in graduate school, Lynn was very impressed by her teacher James F. Crow who taught her General and Population Genetics. Her deep interest in this subject led her to believe that it was only through Genetics that the process of evolution could be reconstructed. She was also fascinated by a form of cellular reproduction that involved genetic material found in a cell's cytoplasm.

The popular notion at the time was that DNA was present only in the nucleus of a cell. Lynn pored through the works of biologists like Ruth

Fig. 1. Lynn Margulis.

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Sager, Francis Ryan and E. B. Wilson. In his book, *The cell in development and heredity*, Wilson discussed the similarities of two cellular organelles — the chloroplast and the mitochondria — to free living bacteria. His book also included references to the works of Konstantin Merezhkovsky and Ivan Wallin. According to Wilson, the Russian botanist Mereschkowsky (1905) arrived at the notion that the division of chloroplasts in green plants closely resembled that of Cyanobacteria (refer **Fig. 2**) based on observations made by the German botanist Andreas Schimper (1883). He, therefore, concluded that green plants may have arisen from a symbiotic union of two organisms. Similarly, Ivan Wallin (1923), an anatomist in the University of Colorado, referred to the symbiosis of bacteria in animals as 'the establishment of micro-symbiotic complexes' or 'symbionticism'. These ideas did not gain much recognition until Stocking and Gifford (1959) discovered that plastids and mitochondria contained their own DNA. This discovery was supported by detailed electron microscopic comparisons between cyanobacteria and chloroplasts by biologists like Hans Ris and Singh (1961). Consequently, the 1960s saw a revival of these explorations, and helped Lynn to further her own ideas on endosymbiosis.

Advancing Endosymbiosis

In 1966, Lynn wrote a paper 'On the Origin of Mitosing Cells' that was rejected fifteen times before it was eventually published in the March 1967 edition of the *Journal of Theoretical Biology*. In this article, Lynn proposed a theory for the origin of eukaryotic cells (cells with their nuclei enclosed within nuclear membranes). She suggested that three components of the cell — namely, its chloroplast (specialized structures in plant cells involved in photosynthesis), mitochondria (the energy generating part of cells), and basal bodies (structures giving rise to flagellum) — were once free-living organisms (refer **Fig. 3**). Lynn postulated that, for example, the mitochondria had originated from a bacterium capable of aerobic respiration. At some stage of evolution, each of these organisms had entered primitive eukaryotic cells, and have permanently resided there ever since. She postulated that interactions between these organisms and primitive eukaryotic cells led to the evolution of new 'hybrid' organisms with components that performed unique life processes. Further evolution of complex life forms initiated as a result of this division of labour. Thus, while the term 'symbiosis' is used to refer to the close association of two organisms, 'endosymbiosis' refers to the merging of two different organisms to form a single new organism. This idea was later explained in detail in her book *'Origin of Eukaryotic Cells'* published in 1970.

Bacteria as enemies?

Bacteria have always been labelled as the cause for diseases waiting to be conquered by the modern weapons of medicine. In contrast, Lynn ceaselessly promoted the idea that bacteria are the under-appreciated designers of Earth's biosphere. In her view, bacteria had already been subject to evolutionary processes for about 2000 million years before other plants or animals appeared on Earth. Not only did they help establish all vital life processes — from

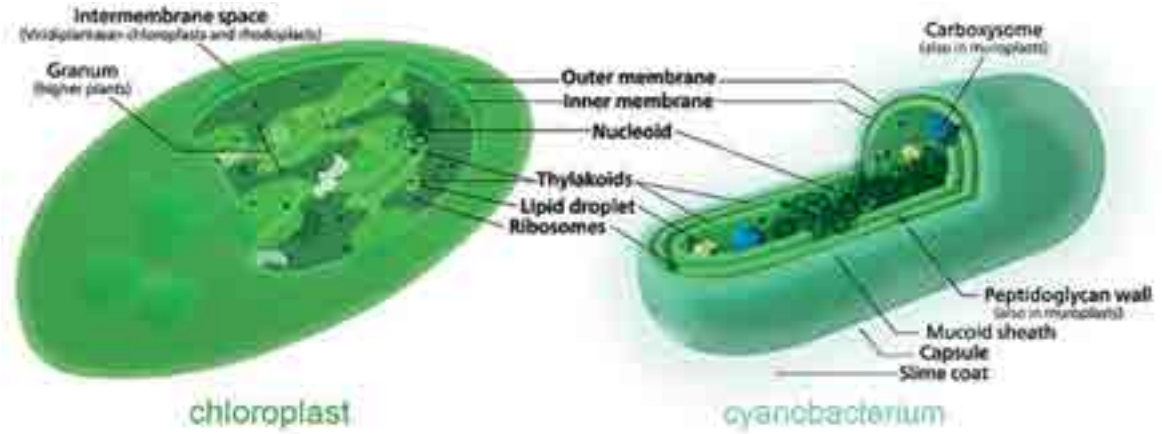

Fig. 2. Margulis's endosymbiotic theory was influenced by the botanist Mereschkowsky's comparison of similarities between choloroplasts and cynabacteria.

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photosynthesis to respiration — that sustain life, but also played key roles in the origin of crucial biomolecules, like DNA, RNA, proteins, etc. According to Lynn, bacteria evolved mainly by sharing genes with each other and forming symbiotic partnerships rather than competing for survival.

In *Acquiring Genomes: A Theory of the Origins of Species* published in 2002, Lynn argued that symbiotic relationships between organisms of different species drive evolution. This argument challenged the Neo-Darwinian ideology that suggested that inherited variations arise mainly from random changes in the genes of an organism (mutation). According to Lynn's theory, this acquisition of mutations, and their accumulation in subsequent generations, is not sufficient to explain how inherited variations occur. Rather, she argued that genetic variation involved the fusion of genomes (the complete set of genetic material in every cell of any organism) of organisms from different species.

Lynn faced a lot of criticism, and even ridicule, in the 1960's and 1970's for her revolutionary ideas, but she went on to defend her theory relentlessly. Today, many biologists believe this remarkable view of eukaryotic cell evolution to be one of the great advancements in 20th century science. This belief is supported by findings of the Human Genome Project that show that substantial sections of the human genome are either bacterial or viral in origin. Also, genome-mapping techniques have shown that family trees of major taxonomic groups appear to be largely cross-linked, possibly due to transfer of genes through bacteria as Lynn Margulis had predicted.

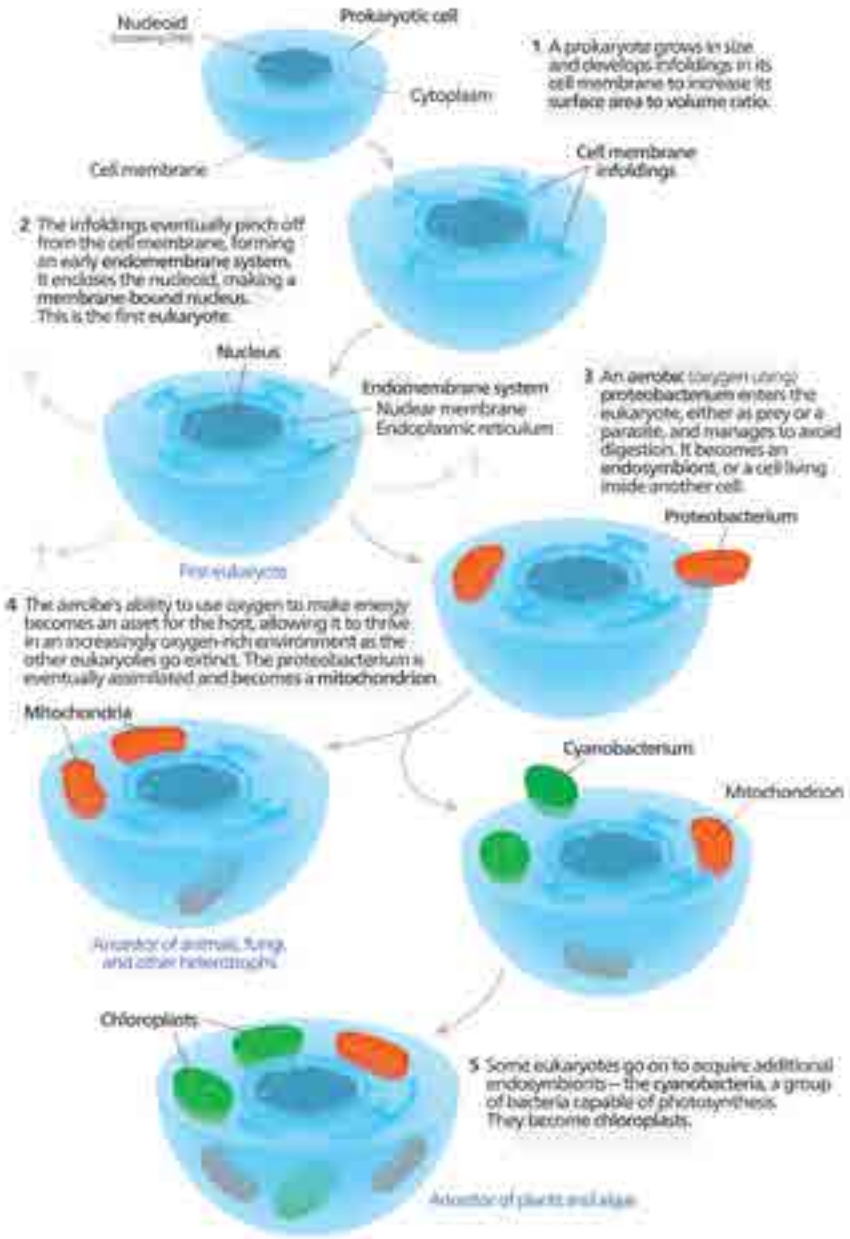

Fig. 3. The origin of eukaryotic cells through serial endosymbiosis.

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Support to the Gaia hypothesis

Lynn's holistic view of Biology led her to support the Gaia (name for the Greek goddess of the Earth) hypothesis proposed by the British biologist James Lovelock (1968). According to this hypothesis, the Earth is a self-regulatory living entity that functions as a unified whole with all living things interacting to create conditions needed for life to continue. Endosymbiosis and Gaia were linked in Lynn's mind as components of a coherent unit that were based on cooperation rather than competition.

However, Lynn's enthusiasm for this hypothesis was not shared by the rest of the scientific community. Many scientists criticised Lovelock's approach in the book *'Gaia, a New look at Life on Earth'* for being teleological, or based on the belief that all things have a pre-determined purpose. Stephen Jay Gould criticised Gaia as being a symbolic description of Earth processes that did not elucidate its actual mechanisms of self-regulation. Realising that this hypothesis invited criticism mostly due to its phrasing, Lovelock made many efforts to remove the teleological elements of the hypothesis. In her book, *The Symbiotic Planet*, Lynn refuted the personification of Gaia and emphasised that Gaia is *"not an organism"*, but

Fig. 4. Lynn Margulis co-authored many books with her son Dorian Sagan.

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"an emergent property of interaction among organisms". But, Lynn's support of this highly-critiqued hypothesis earned her a considerable amount of displeasure from the scientific community. Today, this hypothesis has evolved considerably, becoming a potentially viable and testable scientific hypothesis or theory. Some scientists even believe that the Gaia hypothesis offers us a better understanding of complex environmental problems.

Personal life

In 1957, Lynn married the renowned astronomer Carl Sagan, who she met as a graduate student in Physics while studying at the University of Chicago. The couple had two sons — Dorian Sagan became a famous science writer (refer Fig 4), while Jeremy Sagan founded 'Sagan Technology'. Lynn and Sagan were divorced seven years later. Then, in 1967, Lynn married the crystallographer Thomas N. Margulis, and had two kids with him. But, by 1980, this second marriage had also come to an end. When Lynn was asked about her unsuccessful married life, she expressed her belief that it was not possible to balance the duties of a wife and a scientist simultaneously — one had to let go of one thing to concentrate on the other.

Throughout her life, Lynn advocated science education, especially in less developed countries. She was admired and respected by students across the globe. She held the view that the more students were encouraged to explore the basis of life, the more they'd understand the numerous symbiotic associations around them and, consequently, the idea of evolution. She said, *"If you really want to study evolution, you've got to go outside sometime, because you'll see symbiosis everywhere!"*

Lynn gave talks all over the world, serving as a member of many associations and committees. She worked with NASA, and wrote many books, film scripts, and articles. These, for example, included books like 'Symbiosis in cell evolution' (1981), 'Origins of Sex: Three Billion Years of Genetic Recombination' (1986), 'Microcosmos Colouring Book' (1988), 'Mystery Dance: On the Evolution of Human Sexuality' (1991), 'What Is Life?' (1995), and 'Symbiotic planet' (1998).

Awards and acclaim

Lynn has many honours to her credit. She was elected to both the National Academy of Sciences and The Russian Academy of Natural Sciences. She also received honorary doctorates from several universities. In March 2000, President Bill Clinton presented the U.S. National Medal of Science to her. In 2008, she was awarded the 'Darwin-Wallace Medal of the Linnaean Society of London'. Her papers are permanently archived at the Library of Congress. Just a few days before her untimely death, she was included in the list of twenty most influential scientists alive — one of only two women on this list, which includes scientists such as James Watson, Jane Goodall and Stephen Hawking.

On November 22nd, 2011, Lynn Margulis died of a haemorrhagic stroke. She was 73 years old. In an interview published in the April 2011 issue of the magazine *Discover*, she was asked "Do you ever get tired of being called controversial?" Lynn Margulis replied to this question by stating that: *"I don't consider my ideas controversial. I consider them right"*. Such was the conviction of this great crusader of evolutionary biology, who worked relentlessly towards resolving the mysteries shrouding the evolving of life on this planet.

Note: Credits for the image used in the background of the article title: Lynn Margulis, Distinguished University Professor in the Department of Geosciences at the University of Massachusetts-Amherst speaks during the "Seeking Signs of Life" Symposium, celebrating 50 Years of Exobiology and Astrobiology at NASA, Thursday, Oct. 14, 2010, at the Lockheed Martin Global Vision Center in Arlington, Va. Credits: NASA HQ PHOTO, Flickr. URL: https://www.flickr.com/photos/nasahqphoto/5081810526. License: CC-BY-NC-ND.

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